Brain-Actuated Control of a Humanoid Robot

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BCI Research at the University of Washington

- ECoG (Electrocorticography) based BCI: Uses electrical signals from *surface of human brain* (collaboration with Jeff Ojemann)
  - Talk by Pradeep Shenoy and Kai Miller in afternoon session

- EEG (Electroencephalography) based BCI: Uses non-invasive *scalp measurements* of brain activity
  - Controlling a robot using EEG

- BCI Research in animals: Monkeys (Eb Fetz) and Moths (Tom Daniel)
Overview of EEG-based BCIs

- Approaches based on Event Related Potentials (ERPs)
  - Detect characteristic EEG response to rare/attended-to sensory events
  - E.g., P300 speller [Donchin et al., 2000]

- Frequency-band changes (ERD/ERS)
  - Detect characteristic change in power during actual/imagined motor action
  - E.g., Mu rhythm suppression
  - Max bandwidth in the range 20-30 bits/min

Can EEG-based low bandwidth BCIs be used to control a high DOF robot?

E.g., robotic hands for amputees or a wheelchair/humanoid robot for the paralyzed?
Yes, if the robot is partially autonomous

- Bandwidth of EEG signals may be too low for moment-by-moment control
- …but EEG could be used to provide *high-level commands* to a semi-autonomous robot (cf. work by José del Millán and colleagues)

Example: Fetching an Object

- EEG command: “Go to kitchen”
  - Robot navigates to kitchen
- EEG command: “Pick object X in camera image”
  - Robot picks selected object
- EEG command: “Bring object to me”
  - Robot brings selected object
Problem: Need Robot to be Semi-Autonomous

- Robot needs a set of basic behaviors such as walking, bending, picking up an object, turning etc.
- Programming based on physics/control theory too laborious and fragile
- Idea: Learn new behaviors by watching
  - Learn through imitation and trial-and-error

Learning from Human Motion Capture

(grad student David Grimes)
Learning to Imitate a Human Action

(Grimes, Rashid & Rao, NIPS, 2006)

Learning to Walk

(Chalodhorn, Grimes, Grochow, & Rao, IJCAI, 2007)
Back to the Task: Fetching an Object using EEG

EEG command: “Go to kitchen”
Robot navigates to kitchen
EEG command: “Pick object X in camera image”
Robot picks selected object
EEG command: “Bring object to me”
Robot brings selected object

Using P300 to Select Locations and Objects

Images of Objects
Target object
Other objects
Border Flashes at Random
P300 expected when flashed object is desired target object
Experimental Study Design

- 9 subjects (8m, 1f students at UW)
- 4 sessions of 10-12 min each
  - 2 sessions with a 2x2 image grid (4-choice)
  - 1 session with 2x3 (6-choice)
  - 1 session with 3x2 (6-choice)
- 10 trials per image position
  - Each trial: Subject looks at designated object while borders flash in random order
  - Flashes 0.25s apart with 10 repeats/image
  - Total trial length 10s (4-choice) or 15s (6-choice) for max bit-rate of 12 bits/min

Visually Evoked Response to Target vs. Non-Target
Comparing Responses to Target vs. Non-Target Events

Channel Locations

P300 Classification Method

1. Apply discriminative linear spatial filter [Hoffmann et al., 2006] to reduce 32 channels to ~2-4
2. Band-pass filter [0.5-30Hz]
3. Classify using 2-class linear SVM classifier
4. Maintain running average of classifier output for each choice during trial
5. Output label with maximum average score at end of trial
Learned Spatial Filters

Spatial filters learned *across all subjects*

Results: Classification Error on Test Data
Training an Across-Subject Classifier

Training data from all subjects combined to learn a single classifier.

Tested on each subject’s test data.

Speed-Accuracy Tradeoff

4-class Test Error vs Num Repeat Flashes

- Basic
- BasicAcross
- SpatFilt
- SpatFiltAcross
Task: Use P300-based BCI to command robot to fetch red (or green) object and bring it to one of two tables

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Summary and Future Work

- Low bandwidth EEG-based BCI can be coupled to a 25-DOF humanoid robot for interacting with the physical world.
- Visual feedback from robot camera used in BCI for influencing robot’s behavior.
- Future Work
  - Pushing the envelope on granularity of control
  - Using additional EEG phenomena, e.g., $\mu$ rhythms
  - Endowing robot with adaptive capabilities
    - Robot adapts to BCI user’s environment

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